**Laboratory #6**

# Root Mean Squared Measurements. Transformer Characterization.

## I. Pre-Laboratory Assignments

1. Copy and paste this entire laboratory assignment into your laboratory notebook. Do all of your pre-lab and laboratory work in your lab book in ink. Do not bring any loose paper to the lab.

2. Beginning with the mathematical definition of root mean squared (RMS), calculate the RMS voltage of the sinusoidal waveform described in step 3 of the lab section. Show every step in your calculations.

3. Repeat step 2 of the pre-lab for the square wave described in step 10 of the lab section.

4. Repeat step 2 of the pre-lab for the triangle wave described in step 11 of the lab section.

5. For the DMM used in part 7 of the lab section, determine the approximate maximum frequency for which you would expect the RMS measurements to be accurate. You may wish to consult the user's manual for this device.

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## II. Laboratory Experiments

PART 1: Measure Waveforms Produced by the Function Generator

1. Power on both the Function Generator (RIGOL DG1022) and the Oscilloscope (Tektronix TDS2012).

2. Connect an appropriate cable to channel 1 output of the function generator. Connect a measurement probe to channel 1 of the oscilloscope, and set it to 10x. Connect the cable and probe together (including grounds).

3. Set the function generator output to 10 kHz, 3 $V_{pp}$, sine wave (zero offset). Press 'output.'

4. Adjust the vertical settings (position and volts/div) on channel 1 on the oscilloscope and the horizontal settings (position and sec/div) so that one full period of the waveform can be seen as large as possible on the screen. Use the cursors to measure the peak-to-peak amplitude and the period of the waveform. Record your readings in your logbook.

5. Press the Auto Set button on the oscilloscope to have the waveform displayed automatically. Push the measure button on the oscilloscope, followed by the top button just to the right of the screen. Set the source to channel 1, and the type to Pk-Pk. Push measure>> third button from top>> source=channel 1, type=period. Record your readings and compare them to those from step 4.

6. Push measure>> third button from top>> source=channel 1, type=frequency. Record your reading and compare it to the frequency displayed from the generator. Print a screen shot of the oscilloscope screen showing the waveform and these three measured quantities (Pk-Pk, period, and frequency).

7. Connect the output of the function generator to the Tenma True RMS Digital Multimeter 72-410A. Use the DMM (voltage measurements/AC/proper range) to measure the RMS value of the generated waveform. Also, use it (FREQ/proper range) to measure the frequency of the generated waveform. Record your readings and compare to those measured using the oscilloscope.

8. Organize all of your measured data from steps 4-7 in a table in your logbook.

9. Repeat step 7 above but increase the frequency of the sinusoidal waveform to 400 kHz. Comment on this result. Is it expected? Why? To help answer this question, plot the RMS voltage measured by the DMM from 10 kHz to 500 kHz using a logarithmic scale for frequency (that is, make a semi-log plot).

10. Repeat the steps from 4 to 8 using a function generator output of 5 kHz, 3 $V_{pp}$, square wave (zero offset).

11. Repeat the steps from 4 to 8 using a function generator output of 5 kHz, 3 $V_{pp}$, triangular wave (zero offset).

PART 2: Transformer Characterization

The schematic of the transformer is printed on one side of the device located at your lab station. You may find it helpful to refer to it during this lab.

12. Assume that the four-terminal side of the transformer is the primary [P1 (green wire)/P2 (yellow)/ P3 (blue)/P4 (red)] and that the five-terminal side is the secondary [S1 (black/red)/S2/S3/S4/S5 (black/white)].

13. Connect the function generator output (with the sine wave setting of step 3) to the P1/P4 set of terminals. Connect channel 1 of the oscilloscope to the same terminals (CH1≡primary). Push measure>> 1st button from top>> source=channel 1, type=Pk-Pk (≡Measure#1).

14. Connect channel 2 of the oscilloscope to the S1/S2 pair of terminals (CH2≡secondary). Push measure>> 2nd button from top>> source=channel 2, type=Pk-Pk (≡Measure#2). Calculate the turns ratio $n$ ($=N_s/N_p$) of the transformer as (Measure#2÷Measure#1).

15. Repeat step 14 for all other possible terminal combinations on the secondary side. You might need to press the Auto Set button each time to make sure you obtain correct 'Measure' values. You need to read Measure#1 each time. Organize your data (Measure#1, Measure#2, and *n*) for all terminal combinations in a table. Which combination leads to maximum voltage gain (maximum *n*)? What is its value? What is the connection?

16. Connect channel 2 of the oscilloscope to the terminals that led to maximum *n*. Move the primary terminals (both the function generator output and the oscilloscope channel 1 input) from P1/P4 to all other possible terminal combinations on the primary side. Each time, read Measure#1 and Measure#2, then calculate *n*. Organize your data for all terminal combinations in a table. Which combination leads to maximum voltage gain (maximum *n*)? What is its value? What is the connection?

17. With this later terminal connections, print out the oscilloscope screen.

18. Which terminal connections (on primary and secondary) lead to maximum current gain (minimum *n*)?

19. It is expected that a transformer does not "transform" DC signals from primary to secondary since, due to Faraday's Law, there is no time-varying magnetic flux for a DC current. This characteristic of a transformer is surprisingly tricky to demonstrate in the lab, but that is the intention for this last part.

    a. First, disconnect all the probes and cables attached to the transformer. Measure the DC resistance between the P1 and P4 terminals, and the resistance between the S1 and S5 terminals. Do these relative values make sense to you? Why?
    b. Because the resistance from P1 to P4 is so much smaller, we will use the S1-S5 as the primary side of the transformer for the following measurements. Connect the function generator to S1/S5 and connect channel 1 of the oscilloscope to S1/S5 and channel 2 to P1/P4. Set the function generator to a sinusoid with 3 $V_{pp}$, 4 VDC offset, at a frequency of 10 kHz. Using the oscilloscope, measure the average values of the primary voltage and the secondary voltage.
    c. Next, toggle the function generator (output is now "off") and measure the secondary average voltage. Speculate as to why the voltage hasn't changed from the last measurement, and why it isn't zero. Toggle the function generator output to "on."
    d. Lastly, notice that the average value of the primary voltage is not equal to the offset voltage of the function generator. Explain why. To aid with your explanation, draw an equivalent circuit for the primary side of the transformer that includes the 50 Ω internal resistance of the function generator and the resistance of the primary winding.

## III. Analysis and Conclusions

a) Compare the results of your hand analysis in the preliminary and your data from simulations. Create a table to organize your data comparisons
b) Explain notable differences.
c) Explain why the RMS voltage measured in step 9 of the lab was inaccurate, while all of the other RMS voltages measured in the lab section were accurate.
d) Explain very carefully why your measurements in step 19 demonstrate that a transformer doesn't "transform" DC signals. Very specifically explain why this was difficult to demonstrate in the laboratory.
e) When you are finished with your lab, make a photocopy of all the right side pages and print them out. Turn in your lab at the beginning of lecture on the due date. If you don't have easy access to a photocopier machine, the app GeniusScan works with your smartphone and allows you to easily create a pdf that can be printed.

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† Portions of this lab were adapted from D. Anagnostou, "Lab Experiment – 6," 2015.